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Development of a Methodology for Understanding the Potency of Risk Connectivity

Neil Allan
Visiting Fellow University of Bristol Systems Centre, UK
Yun Yin
University of Bath, UK

***Abstract*—The Strategic Risk Register System (SRRS) is proposed by the authors as a practical methodology to enable the connectivity of risks to be elicited and evaluated so that the most potent risks in a system can be identified. The SRRS methodology builds on the impact × likelihood paradigm by introducing a connectivity matrix to modify traditional risk registers and uses graph theories to depict the relations between risks. Several techniques are employed to visualize and interpret the significance of the results. A case study is used to demonstrate how the SRRS works in practice. This paper builds on the 3-year research programme called STRATrisk, commissioned by the Department for Trade and Industry (Dti) in the UK, which reported that the assessment of the interconnectivity of risks is necessary to understand key risks in complex systems.**

INTRODUCTION

With the progress of globalization, more people are endeavoring to understand risks in alternative ways. Sociologist, Ulrich Beck (1992), in his seminal paper, *Risk Society*, implied that people can no longer make decisions with certainty or complete information. He argued that the incremental changes in social practices and knowledge in a modern society eventually exposes that society to complex and significant risks that are created by the spontaneous interconnectivity of those small hidden changes. He highlighted risks are no longer confined within certain boundaries and they are easily distributed and spread.

Beck (1992) reminds us that risks are related to people's decision making. The perceived complexity and ambiguity of modern decisions leads to decisions and associated risks being fueled by ignorance or biased knowledge. Campbell and Currie (2006), suggest that conventional risk approaches cannot deal with the immeasurability of modern risks, leading to people's incapability in understanding current risks. Recent failures of financial institutions caused by complex derivatives shows that even professionals can be overwhelmed by the ambivalence and incalculability of risk

The civil engineering industry is not immune from such global turbulence. Many large companies have disappeared or suffered from sharp drops in profits. Allan et al (2007) refer to these as strategic risks and recommends that system thinking provides a way to manage the systemic behaviour of emerging risks by understanding their interconnectivity and structure.

The aim of this paper is to help engineering companies capture a holistic view of their strategic risks and provide a practical methodology to achieve that objective. The following section will briefly review current risk management practices, along with an overview of the systems thinking philosophy used in our approach. We then provide details of the Strategic Risk Register System (SRRS) methodology, including a case study to demonstrate the application and implementation issues.

BACKGROUND

Risk and Risk Management in Practice

Risk is often described as 'an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective' (PMI, 2000). In broader terms, risk 'reflects variation in the distribution of possible outcomes, their likelihoods, and their subjective values' (March and Shapira, 1987). Mathematically, risk is 'the probability of occurrence of loss/gain multiplied by its respective magnitude' (Jaafari, 2001), or

$$R = I \times L \quad (1)$$

In practice, the specific context of risks is also important and defined differently across industries and functions of a company, e.g. financial risks, human resource risks, market risk, legal risk, etc (Pickford, 2001). Moreover, risk management has become an integrated part of management functions. Although risk management tends to be tailored to a firm's industry and strategy, it is not hard to identify commonalities. Pickford (2001) identifies 7 key risk management processes: identification, assessment, analysis, design, implementation, review and audit. Furthermore, some risk management techniques are more prevalent, such as Critical Path Analysis (CPA) (Pierce, 1998), Failure Mode and Effect Analysis (FMEA) (Mikulak et al, 1996), Probability and Impact Grids (Stewart and Melchers, 1997), and Monte Carlo Simulations (Goodwin, 2004). Yet risk registers remain the most common risk management tool used by engineering companies (Crossland et al, 1998).

Some of the Recent Trends

Both academics and practitioners continually innovate risk management to meet the challenges of uncertainty in modern risks. Ward and Chapman, (2003) advocate that risks should be treated as uncertainties, using a reflective approach and an open modifiable strategy. Recent research (Allan and Davis, 2006, Merna, 2005) tend to integrate complexity and systems thinking into risk management. In particular, Allan and Davis (2006) suggest that risk behaves as a complex system and has a hierarchy of influences, such as strategic, project and operational. The natural development from this complex systems approach is that individual risks are by definition connected to other risks in the risk system, albeit to a lesser or greater extent. The challenge for risk managers is to identify and measure the strength or potency of these risk connections so that risk emergence can be identified and controlled (Nielson 2006).

Risk Registers

Conventionally, a risk register is 'a repository of a corpus of knowledge' and 'initiates the analysis and plans that flow from it' (Williams, 1993 and 1994). In most cases, a risk register contains relevant information of a risk, including the description of the risk, its impact, its probability of occurrence, owner of the risk, reduction and mitigation plan. Among those features, the most prominent ones are the impact and the probability of occurrence, both of which have severe limitations in an uncertain environment.

The two-dimensionality of risk, in terms of impact and probability, cannot provide a solid and robust foundation for understanding risks in a risk register (Williams, 1996). Only through understanding the interconnectivity of risks does the decision maker arrive at a holistic view of the risk system (Allan et al, 2007). However, current techniques do not consider the interconnectivity of risks or measure the consequence of connections. Risks continue to be analyzed in isolation to other risks which of course is not what happens in real life.

Interestingly, risk registers are used at different levels in larger organisations and projects, with high probability and high impact risk being escalated to the next level in the hierarchy. Very rarely do senior managers attend to risks in a register lower down the project or organisational structure. Yet, the hidden small changes in risks, distributed across risk registers in the organisation and yet connected in some, can reveal systemic risks brewing just under the normal detection radar. Current risk registers can easily be extended to provide the richness of information to senior managers that are required to spot emerging risks.

System Thinking

Systems thinking aims to recognize, organize, analyze, and resolve problems systemically (Checkland and Scholes, 1990). System tools can be roughly categorized as hard or soft system approaches, and the combination of tools required depends on the issues or problems that are to be resolved. After defining a specific system or problematic situation, boundaries and elements can be identified. Then, related objects or concepts can be modeled together within this framework. Although there is no single system approach, they share common characteristics which have been demonstrated to help manage uncertain, dynamic and complex environments (Checkland and Scholes, 1990).

One such approach is cognitive mapping. Typically, not all necessary information and knowledge is available, so decision makers have to utilize their heuristic judgments to rationalize the decision-making behaviour. In this sense, it is necessary to depict and explore the cognitive structure of decision makers (Walker, 2005). If participants' expert knowledge can be elicited, this method can be highly effective. Methods such as: causal mapping, semantic mapping, and concept mapping, are valid and reliable, (Buzman, 1993, Huff, 1990, Keng and Xin, 2006, and Eden, 1998). Additionally some mathematic techniques, such as graph theories and factor analysis, can be employed to explore further connections in the cognitive maps.

Summary

Current risk management techniques cannot sufficiently manage risks due to the constraints of two-dimensionality and therefore it is necessary to rethink the problem from the conceptual level. Systems thinking provides a new way of understanding risk behaviour. This leads to a more reflective approach towards risks and emphasis the interconnectivity between risks..

To implement these concepts, especially in an engineering management context, we propose a methodology to add new elements to conventional risk registers and hence allow people for understanding the emergent properties of the risks.

OUR APPROACH

Soft systems approaches (Checkland 1990) and cognitive mapping have been proposed to aid holistic thinking and the understanding of the interrelatedness of risks (Lewin and Allan 2006). However, these techniques are unfamiliar to engineering managers. There is a need to develop techniques that can introduce the complexity of interconnectivity, whilst remaining familiar and pragmatic. Using existing risk register and integrating risk's third dimension, connectivity, can complement current methodologies. We propose the Strategic Risk Register Systems (SRRS) that uses linear algebra and graph theories to calculate and visualize connectivity between risks.

Assessing Risks

In the next section risk factors are denoted as R_1, R_2… R_z. The impact of a risk and its probability of occurrence is simplified as impact (I) and likelihood (L) and they are measured with traditional qualitative or quantitative methods. The output from this process can be recorded as L_1, L_2…L_z, and I_1, I_2…I_z respectively.

It should be noted that the qualitative descriptions are translated into the quantitative terms. For example, a series description of 'high, medium, low, and negligible' may be quantified as '1, 0.5, 0.1, and 0.05'. Detailed techniques to transform qualitative measures into quantitative terms can be found in (Goodwin, 2004) but there are two special considerations for selecting 0.05 as the lower end of the scale rather than zero. Firstly, system literature, (Marchal, 2003), suggests that when taking a holistic approach to a system, all elements are potential connected and secondly a 0.05 or 0.01, is adopted by statisticians as being of negligible significance (Newbold et al, 2007).

An elicitation process of connectivity is needed to ensure participants adopt a reflective approach in thinking about risks. Ren (1994) states that risk can 'mutually affect, impede and promote each other' and the relationship between risks can be 'independent, dependent, parallel and series'. Also, hierarchical influences, geographical adjacency, logical sequential order and timeliness shall be taken into consideration. The connectivity of risk factors can be derived pair-wisely and measured using the same range between negligible (0.05) and extremely high (1). Individual connectivity can be coded as C_{12}, $C_{13} \ldots C_{mn} \ldots C_{(z-1)z}$, and allocated into Matrix (2).

$$\text{Connectivity Matrix: } \begin{bmatrix} 1 & C_{12} & C_{13} \ldots C_{1Z} \\ C_{21} & 1 & C_{23} \ldots C_{2Z} \\ C_{m1} \ldots\ldots C_{mn} \ldots\ldots \\ C_{z1} & C_{z2}, \ldots\ldots\ldots\ldots 1 \end{bmatrix} \quad (2)$$

Processing and Visualizing Data

With the SRRS the individual risk factors are measured with three parameters, likelihood (L), impact (I) and connectivity (C). In traditional approaches, the expectation of an individual risk equals likelihood (L) times impact (I), which is demonstrated in Equation (1). The potency values of risks can be obtained by integrating the expectations (R) and connectivity (C) values using the algorithm below in Equation (3):

$$P(Potency) = (R_m + R_n) \times C_{mn} \quad (3)$$

Where m and n indicates the m-th and n-th risk. If m equals n, we assume the potency value equals the expectation value of the risk. Moreover, since values of likelihood and impact can be ordinal or interval numbers, the value of the outcome P, stands for either relative or absolute values respectively.

Equation (3) indicates that the potency of a pair of risks is not only determined by the robustness of connectivity itself, but also by the expectations of risk factors. On the other hand, the influences of this risk pair are adjusted by their interconnections. This approach allows for risks to activate others risks and vice-a-versa. The potency values are located in Matrix (4).

$$\text{Potency Matrix: } \begin{bmatrix} R_1 & P_{12} & P_{13} \ldots P_{1Z} \\ P_{21} & R_2 & P_{23} \ldots P_{2Z} \\ P_{m1} \ldots\ldots P_{mn} \ldots\ldots \\ P_{z1} & P_{z2}, \ldots\ldots\ldots P_z \end{bmatrix} \quad (4)$$

As each value on the diagonal of the matrix influences both the column and row in which it is located, it is straightforward to normalize the matrix and to elicit the relative importance of each risk. The method we used for this is similar to one of the normalization methods that are proposed by the Analytical Hierarchy Process (AHP) (Saaty, 1980), which is:

1. Calculate the mean value of a row and locate it into every grid in the row;
2. Calculate the mean value of the column and locate it into every grid in the column;
3. Calculate the weighted value of every gird by averaging column and row values for that grid.

The results can be demonstrated in Matrix (6):

$$\text{Normalized Potency Matrix: } \begin{bmatrix} P'_1 & P'_{12} & P'_{13} \ldots P'_{1Z} \\ P'_{21} & P'_2 & P'_{23} \ldots P'_{2Z} \\ P'_{m1} \ldots\ldots P'_{mn} \ldots\ldots \\ P'_{z1} & P'_{z2}, \ldots\ldots\ldots P'_z \end{bmatrix} \quad (5)$$

For any grid in Matrix (4), the normalized potency value is

$$P'_{mn} = \frac{\sum_{m=1}^{z} P_{mn} + \sum_{n=1}^{z} P_{mn}}{2z} \quad (6)$$

Values on the diagonal of Matrix (5) represent the potency of individual risk factors correspondingly. Furthermore, the normalized potency matrix can be visualized using graph theory. Every value in an adjacency matrix can indicate the causal or other logic relationships between the two variables, including the connectiveness (Wilson, 1996). Matrix (5) can be transformed into an adjacency matrix by selecting criteria to determine whether a potency value is tolerable for the business or not. Then, risks can be displayed as nodes, and potency values of risk pairs can be viewed as the edges between nodes. We therefore have the ability to represent the inter-connectivity of a risk system which gives an understanding of which are the key potent risks and why.

Thus, risk factors can be ranked and prioritized. Numerically, the greater potency value is, the more important a risk is; graphically, the more connected a risk is, the more important it is. This approach allows for the visualization of how risks are interrelated and structured. It also provides a story of how risks can develop and propagate thereby enabling managers to put in place appropriate mitigation measures. Detailed steps of this process are explained in the case study example below.

CASE STUDY

A simplified real case study has been selected to demonstrate the implementation procedures of the SRRS and provide an example of the reflective insights that can be achieved from the graphical representation of the connectivity. The case study draws on experience from a large UK civil engineering company and one of the project level risk registers was selected as the data source. The connectivity values were elicited from the project team via interview and a spreadsheet-based questionnaire. For clarity, the size of the SRRS is reduced to six columns and rows though the software can, theoretically at least, accommodate any number of risks .

THE CASE STUDY

Data Input and Processing

The simplified risk register of the civil engineering company is presented in Exhibit 1.The values of likelihood (L) and impact (I) and connectivity (C) are derived from the results of a five-interval, or six-point, Likert Scale questionnaire. Participants illustrate their qualitative description of the scale, in terms of negligible, quite low, low, high, very high, and extremely high. After discussing the relative importance of numerical values, we attribute 0.05, 0.1, 0.2, 0.5, 0.8 and 1 to qualitative descriptions correspondingly. For example, if interviewees consider 'insufficient financial supply (C. Financial Risk) is likely to interrupt daily operation of the project team (B. Operational Risk)', the connectivity of the two risks can be recoded as C_{32}=0.8 and it will go to row 3, column 1. All the connectivity values are then inputted into the matrix as demonstrated in matrix (7).

[Insert Exhibit 1]

Example of Connectivity Data Input Matrix:

$$\left[\begin{array}{lllllll} & A & B & C & D & E & F \\ A & 1 & 1 & 0.8 & 0.8 & 0.2 & 0.8 \\ B & 0.5 & 1 & 0.5 & 0.8 & 0.5 & 1 \\ C & 0.8 & 0.8 & 1 & 0.8 & 0.5 & 0.2 \\ D & 0.2 & 0.2 & 0.5 & 1 & 0.05 & 0.8 \\ E & 0.05 & 0.2 & 0.1 & 0.1 & 1 & 0.2 \\ F & 0.5 & 0.05 & 0.2 & 0.05 & 0.05 & 1 \end{array}\right] \quad (7)$$

The potency values of every risk and every pair of risks can be calculated using Equation (1) and (3) and the results are demonstrated in the following matrix (8):

$$\text{Potency Matrix:}\left[\begin{array}{lllllll} & A & B & C & D & E & F \\ A & 0.1000 & 0.3000 & 0.4000 & 0.0960 & 0.0240 & 0.1120 \\ B & 0.1500 & 0.2000 & 0.3000 & 0.1760 & 0.1100 & 0.2400 \\ C & 0.4000 & 0.4800 & 0.4000 & 0.3360 & 0.2100 & 0.0880 \\ D & 0.0240 & 0.0440 & 0.2100 & 0.0200 & 0.0020 & 0.0480 \\ E & 0.0060 & 0.0440 & 0.0420 & 0.0040 & 0.0200 & 0.0120 \\ F & 0.0700 & 0.0120 & 0.0880 & 0.0030 & 0.0030 & 0.0400 \end{array}\right] \quad (8)$$

As described above, because each value in the matrix is affected by the value on the diagonal, Matrix (8) can be normalized. Matrix (9) then contains the final potency values for individual risks which are highlighted.

$$\text{Normalized Potency:}\left[\begin{array}{lllllll} & A & B & C & D & E & F \\ A & \mathbf{0.1485} & 0.1760 & 0.2060 & 0.1389 & 0.1168 & 0.1310 \\ B & 0.1605 & \mathbf{0.1880} & 0.2180 & 0.1509 & 0.1288 & 0.1430 \\ C & 0.2220 & 0.2495 & \mathbf{0.2795} & 0.2124 & 0.1903 & 0.2045 \\ D & 0.0915 & 0.1190 & 0.1490 & \mathbf{0.0819} & 0.0598 & 0.0740 \\ E & 0.0732 & 0.1007 & 0.1307 & 0.0636 & \mathbf{0.0414} & 0.0557 \\ F & 0.0805 & 0.1080 & 0.1380 & 0.0709 & 0.0488 & \mathbf{0.0630} \end{array}\right] \quad (9)$$

Data Interpreting and Visualizing

In the original Risk Register, risks are treated as a set of isolated factors. In some circumstances, the importance of individual risks cannot be distinguished, i.e., D and E. Bringing the connectivity of risks into consideration, a greater understanding of the risks is presented. Values on the diagonal of Matrix (9) indicate the relative importance of the potency values of risk factors, which can be utilized to assist decision makers to focus on the risk that may seed the system. In this case, risk factor D has a greater influence than E, the political risk, and therefore D needs more attention from key decision makers.

Furthermore, an adjacency matrix can help capture a visual representation of the result. The first step is to select a potency value, which indicates the risk tolerance. For example, if a manager adopts a risk-averse approach and cannot tolerate risky behaviour in the project process, he or she may choose a relatively low potency value. This will lead to more risks are connected and thus the manager has to tender the individual risks as well as the connected part of the risk system. On the other hand they may select a larger potency value, allowing the identification of the most influential risks.

Then, the adjacency matrix can be obtained by comparing values in the Normalized Potency Matrix (9) with the pre-selected potency value. If a value in Matrix (9) is greater than the pre-selected potency value, it can represent an edge, connecting a risk pair, and the value can be recorded as 1 in the adjacency matrix. Otherwise, the value in the adjacency matrix is 0 correspondingly. It should be noted that the diagonal of the adjacency matrix is intentionally left blank since the self-connectiveness is not relevant to this paper. For instance, if the potency value is selected as 0.15, the adjacency matrix can be obtained as

$$\text{Adjacency Matrix:}\begin{bmatrix} 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (10)$$

Thus, the adjacency matrix can be visualized as what we refer to as a Risk Map. It is illustrated as Exhibit 2:

[Insert Exhibit 2]

With the change of pre-selected potency value, a series of risk maps can be drawn. The following table demonstrates how the risk factors are connected four in different scenarios

[Insert Exhibit 3]

Implications

There are several implications that emerge from the SRRS approach:

- The potency of risks is represented as the values on the diagonal of the normalized matrices. Through potency measures risks can be understood more holistically which is particularly important for complex organisations.
- The selection of a potency value is largely determined by the risk appetite and availability of risk management resources and is also useful as a what-if tool.
- Risks with strategic importance can be identified.

Managers can interpret the risk management resources quantitatively in terms of potency value, or they can simply observe the change in shape of the risk map with different potency values. The more connected, the more important a risk is. In this case study, Financial Risk (Risk C) is crucial for the civil engineering company and is the key strategic risk in this project, not surprisingly perhaps. .

- Risks with similar ratings in conventional approaches are now differentiated. D is more important than B and managers might want to revisit the importance of this.
- The risk maps can change when selected potency value changes. This indicates that when risk management resources become critical, which could be expressed as the increase of potency value, some risks will be decoupled from the connected part of a map and become isolated. For instance, when the potency value is selected as 0.65, Risk B and E are disconnected suggesting that managers should place more focus on the connected part of the risk map.
- Risk management strategies can be designed to target key nodes. For instance, when Risk C is controlled, the overall structure of the risks is much simplified. Also interventions can be planned to control the domino effects of risks more effectively
- The reaction mechanisms of the risk set can be understood. The potential interaction between new risks and current risks is not well treated using conventional techniques but SRRS is useful in making the cause and effect more explicit.
- Researchers (Thompson, 2002; Allan and Davis, 2006) point out that effective communications of risk issues is essential to achieving effective risk strategies. The 'risk map' shows the necessary path of communication that will help mitigate the propagation of risks

CONCLUSIONS

This paper proposes that connectivity is the third dimension of risk and introduces the concept of a risk system. A method of investigating the interconnectedness of risks within a risk register framework is proposed to provide a more holistic analysis of risk. A case study has been provided to demonstrate the approach in practice. The advantage of visualizing the connectivity of risks is significant but raises the issue of data collection and interpretation. Further research into streamlining the data collection methods and integrating multiple layers of risk register are ongoing.

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Figures and Tables

Exhibit 1: Risk Register

Risk Factor	Impact (I)	Likelihood (L)	Expectation (I×L)
A. Technology Risk	1.0	0.1	0.1
B. Operational Risk	0.50	0.40	0.20
C. Financial Risk	0.80	0.50	0.40
D. Legal Risk	0.20	0.10	0.02
E. Political Risk	0.20	0.10	0.02
F. Reputation Risk	0.80	0.05	0.04

Exhibit 2: Risk Map at Potency Value = 0.15

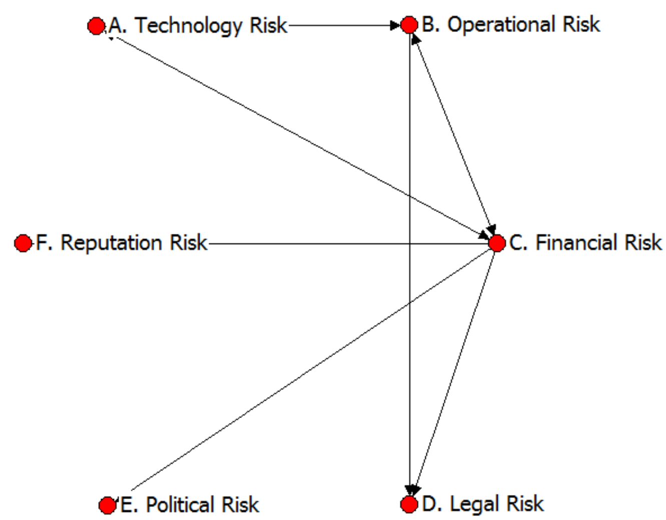

Exhibit 3: Risk Maps at Different Potency Values